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Convergence of European wheat yields

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ABSTRACT

The paper makes several contributions to the study of wheat yield changes in Europe and the resulting economic consequences in the near to medium term future. In particular, it addresses the issue of the effects of yield changes on land use. The transition and growth of yields are estimated using a combination of convergence, time-series and dynamic panel models. Scenarios are then run using estimated yields as input into a computable general equilibrium (CGE) model. The CGE model provides a narrative framework through which the total economic impact of changes in yields can be analyzed. Together, the complementary approaches of econometrics and general equilibrium models allow a more complete economic analysis of the consequences of yield changes for this important biofuels crop to emerge. Although there is no evidence of a common rate of yield convergence across Europe, there is evidence of absolute convergence. Standard time series and panel forecasting methods indicate the potential for only very modest yearly yield increases across most of Europe given optimistic assumptions; although potential yearly increases in newer European states could, in some cases, be substantially higher. However, the total amount of land released as a result of potential yield increases in the wheat sector is only modest because of an increase in demand for land by sectors other than wheat. The overall question of whether significant yield increases will necessarily lead to large increases in land available to produce bio-energy crops is rejected. Land freed by wheat yield increases will go to the production of a wide range of agricultural products that value it as an input. The same reasoning which links yields and land use applies to all agricultural products when there are well functioning markets.

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1. Introduction

1.1. Issue

The paper addresses the effects of forecasted yield increases on land use in the European agricultural sector. The argument linking yields and land use is that technological advances which lead to increased yields will provide a means to circumvent the difficult trade-offs required to meet the various demands for biomass products [13,53,55]. The claim is that an increase in yields will mean that less land will have to be used to produce the same amount of crops, thereby avoiding or at least mitigating a part of the land use effects incurred when converting agricultural and non-agricultural lands into bio-energy crop production. Furthermore, given that a large component of the total costs of producing bio-energy products is the cost of the crop used, technological improvements that increase yields are expected to have positive economic consequences for bio-energy products in terms of prices and quantities produced [22]. This follows because crops are the principle cost of producing first generation biofuels; estimated biofuel share costs in Europe are approximately 70% for sugar beet, 75% for wheat, rye and maize, and 80% for rapeseed oil [37].

A review by de Wit et al. (2011) summarizes the findings of four reports that calculated the amount of additional land made available from yield increases [55]. The main argument in those reports is that yield increases will release land which is currently being used to grow crops to grow bio-energy crops and, particularly, crops to produce biofuels [14,16,17,19]. The calculated amount of land released for the production of biofuels in those studies is the hypothetical maximum in that each of the studies assumes that any land that is freed (in the case of the REFUEL study, 60 million hectares) will go to bio-energy production rather than the production of food, feed or fiber. Furthermore, it has been argued that a large potential source of production gains might come from expected yield increases in the newer states of Europe. Current yields for those countries are far below the European mean, suggesting that yields there are due for an increase. It follows that the question of whether yields in Central and Eastern Europe will converge to those in Western Europe will largely determine whether yields in Europe as a whole will increase.

It is self-evident that yield increases reduce the amount of land required to grow crops, all else equal, but *how* the freed land will be used depends on wider economic and social considerations. The argument underlying the conclusions of the studies mentioned rests on two assumptions. The first is that the land made available from increased yields will go to produce bio-energy crops rather than for some other use. Secondly, and more fundamentally, it assumes that there will be a demand, at a competitive price, for products which use bio-energy crops. Demand for such products is a necessary conditions, but by no means a sufficient condition for increasing the production of bio-energy crops. This paper addresses the first issue, in short, it asks what will be produced on freed land resulting from yield increases. The answer to the second issue, not addressed here, is largely dependent on government policies and the prices of petroleum and other bio-energy crop substitutes [49].

Land use has been an important consideration in assessing the economic viability and environmental impacts of biofuels and other biomass products since Searchinger et al.'s [44] paper first raised the issue. Searchinger et al.'s paper and many others which followed, have put land use on the political agenda as well, indeed, mitigating the negative effects of land used to produce biofuels is an important part of the European Biofuels Directive (2009/28/EC) [15]. While other researchers have used computable general equilibrium (CGE) models to address the issue of the effects of bio-energy crops on land use [25,26,41,33], our modeling framework differs to previous studies by introducing explicit econometric models to forecast yields as opposed to using standard yield assumptions of CGE models which are often difficult to reconstruct and reproduce. In addition, land use in MAGNET, the CGE model we use, has a sophisticated land supply module allowing us to better model the effects of yield changes on land use. It is the combination of econometric forecasting methods and the improved CGE framework which distinguishes our work and allows us to more fully address the research question.

The structure of the remainder of the paper follows directly from the main research question. In order to answer that question, we first need to determine the extent to which yields will increase in the future. We briefly discuss the data used in the analyses and then apply various techniques to understand the trajectory in which wheat yields have been following. We then build an econometric model in order to forecast yields. The forecasted yields are then used as input into MAGNET in order to assess their impact on land use.

2. Data and methodology

2.1. Data

2.1.1. FAO data

The study consists of two main parts. The first attempts to forecast European crop yields and the second calculates the economic consequences of those increases. All of the data used in the econometric analyses are publicly available and an effort has been made to be as explicit as is practicable about the techniques

used with the aim to ensure reproducibility. The FAO data spans a period from 1961 to 2010 and measures hectograms of wheat produced per hectare [18]. In some instances, particularly in the panel econometric analyses, only the years between 2001 and 2009 are used. The year 2001 was chosen because it appears to be the first stable year for yields following the economic changes resulting from political events in the Central and Eastern Europe which form the bulk of the newer countries in the study. The year 2009 was chosen because it is the latest year for which Penn World Trade data is available. Whenever possible, country level data is used, in other words, FAO yields per country are used in the analyses rather than, say, aggregated group data. Aggregated data have well documented limits when used in econometric analyses [4].

2.1.2. Penn world trade data

GDP data from the Penn World Trade version 7.0 is used in the analyses [28]. In particular, the variable constant price GDP per capita and expenditure shares is used as an exogenous variable to explain changes in yields. The GDP data is meant to provide a rough estimate of the wealth and technological development of a country. The assumption is that rather than a particular legislative policy such as in de Wit et al. (2011), a good *general* variable associated with yields is a country's GDP per person. This variable has been widely used throughout the convergence literature as *a* measure of economic development at least since the Solow-Swan and Ramsey economic growth models [46,42]. Whereas those models use marco-variables such as capital, labor, and technology to explain differences in real GDP rates across countries, we use real GDP per person as a proxy for those other variables. In short, we are not trying to explain the causes of yield increases, such an exercise would involve using data that does not exist at the macro level or is of poor quality for many of the newer European countries (it does exist for established European countries). Rather, we are using real GDP per person to test whether changes in that variable result in econometrically significant changes in yields. Other explanatory variables such as land supply, labor, and fertilizer use were considered as exogenous variables, but their availability and quality, particularly for Central and Eastern European countries, led us to the conclusion that more countries could be included in the analyses by using real GDP per person as a catch-all for economic development and as a measure of the capabilities of countries to increase their yields. We are not the first to observe the strong correlation between real per person GDP and yields (for example, see Hafner [23]). Finally, in a few cases, less than 1% of the total number of data points used, a year of yield or GDP data was missing from the FAO or Penn World Trade databases. This is particularly true in the first years of the analysis of the newer European countries. If a country was missing data, then a simple linear prediction method was used to estimate the missing year. Essentially, a linear regression was run and the resulting relationship was used to estimate the missing point.

2.1.3. MAGNET data and behavior

The global economic simulation model used in the analysis is the Modular Applied GeNeral Equilibrium Toolbox (MAGNET), a CGE model developed at LEI which is a part of Wageningen University and Research Centre in the Netherlands [52]. MAGNET has been extensively used to study the impact of policy changes on international trade, production, consumption, prices and the use of production factors such as land, capital and labor [47,50,51]. It is an extension and significant reorganization of the Global Trade Analysis Project (GTAP) model, a widely used tool for global trade analyses [27]. Extensions include more refined production and consumption structures, and, of particular importance to the current study, MAGNET has a more sophisticated land market module which makes it particularly suitable for land use analyses. Below follows an intuitive description of the model, including the data base which forms the heart of the model, the modeling of actor behavior and markets, and a description of the land supply module.

The data used in the analysis is based primarily on version 8 of the database collected and processed by Global Trade Analysis Project (GTAP). Version 8 uses 2007 as its base year and contains balanced economic data for 129 regions and 57 economic sectors. For the purpose of this analysis, the 129 regions and 57 sectors have been aggregated into more meaningful categories. In a CGE model, the data for all regions and sectors must be included in the analysis in one form or another. Aggregation allows less important data to be bundled together and focus to be directed on specific regions and sectors. A practical reason for aggregating is that it allows a model to solve in a reasonable period of time. The regional aggregation used in the analysis consists of twelve large European wheat producing countries as reported by the FAO in 2010. All other regions in the world have been aggregated into a category labeled 'Rest of World' (ROW). The sectoral aggregation consists of 12 primary agricultural sectors, including wheat, available in MAGNET. The remaining sectors have been aggregated into a manufacturing and a service sector. The model retains the standard MAGNET specification of five factors of production, including skilled and unskilled labor, capital, land and natural resources. The land use data used in MAGNET were obtained from data compiled by GTAP in a two-step process [21]. First, SAGE (Center for Sustainability and the Global Environment) land cover data for 2004 are corrected for the percentage change over 2004–2007 as reported by FAO [48]. In a second step, the data are distributed over crops in proportion to harvested area using data from SAGE/FAO, and over livestock sectors using data on value add of land in those sectors.

MAGNET captures the behavior of three types of agents: households, firms, and government, for each of the regions in the model. Household behavior is captured via a representative regional household which aims to maximize its utility, collects all income that is generated in the economy, and allocates that income over private households, government expenditures, and savings for investment goods. Income is derived from payments by firms to the regional household for the use of endowments of skilled and unskilled labor, land, capital and natural resources. The regional household also receives income from taxes paid by the private household, firms, and government expenditures. Firms, profit maximizers, produce commodities by employing the aforementioned endowments and intermediate inputs from other firms using a constant returns to scale production technology and sells them to private households, the government, and other producers. Domestically produced goods can be either sold on the domestic market or exported. Similarly, intermediate, private household, and government demand for goods can be satisfied by domestic production or by imports.

Demand for and supply of commodities and endowments are traded in markets which are perfectly competitive and clear via price adjustments. Because all markets are in equilibrium, firms earn zero economic profit, households are on their budget constraints, and global savings must equal global investments. Since the CGE model can only determine relative prices, the GDP deflator is set as the numéraire of the model against which all other prices are bench marked. Changes in prices resulting from the model simulations therefore constitute real price changes. For the current study, we are using the model to carry out dynamic analyses over time, specifically for 2007 (the base year) until 2020. Projections into the future are obtained by allowing the exogenous endowments of capital, land, natural resources, and labor, and the

productivity of these factors, most notably yields, to grow according to specified growth paths which are based on a readily available economic data.

2.1.4. MAGNET's land supply curve

Land supply is modeled in MAGNET using a land supply curve which specifies the relationship between land supply and a land rental rate [29]. The general idea underlying the land supply curve specification is that the most productive land is the first to be put into production. However, the potential land available for use in agriculture production is limited. If there is a relatively large amount of land available to meet an increase in land demand, then rental rate increases will be modest (see Fig. 1). That situation is depicted by points situated on the left, flat, part of the land supply curve. However, when agricultural land is scarce, an increase in demand for agricultural land will lead to large increases of land rental rates as the available land supply approaches the asymptote in Fig. 1.

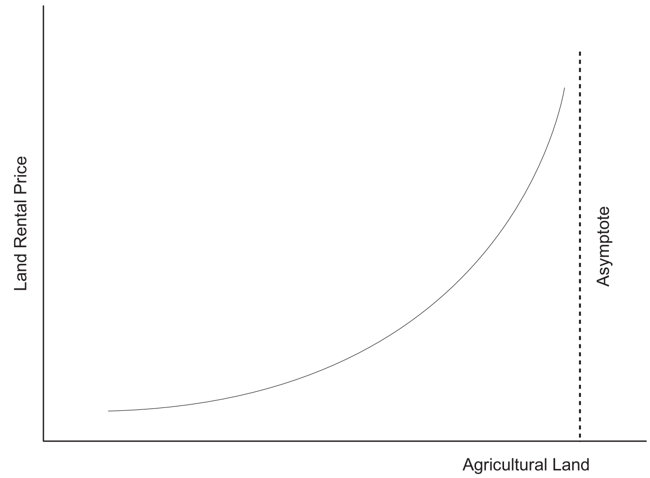

Fig. 1. Land supply curve.

2.2. Econometric methodology

An important first step to test our main research question is to forecast yield increases in Europe. Several complementary methodological approaches are employed to conduct this step of the analysis. In the first step, the current state of wheat yield increases is presented and analyzed using univariate and standard time series econometric techniques. Analyses are, whenever possible, presented via figures. The objective of this step is to determine the general shape of the data and to identify differences across Europe and between Europe and the world. Thereafter, a model of convergence is presented in order to test whether yields in Europe are converging to a common level, and, if so, at what rate. If the yields of European countries are converging, then forecasting future yields is a relatively simple matter as yields in newer European states can be expected to be more or less similar to those in established Europe at some calculable point in the future.

Once this first step has given us an overview of yield trends, we can begin the process of specifying a model to forecast yields. Two approaches are considered, a country level, time series approach and models based on panel data. There are clear trade-offs between the two approaches. The time series approach uses well-established methods to forecast yields per country. This approach benefits from long data series, unfortunately, several Central and Eastern European have only very short series. The panel approach can be used with shorter series because it, essentially, combines data across countries so that many short series amount to one long series. The problem is that panel models are only helpful if the underlying data generating mechanisms of countries are reasonably comparable. The matter of choosing between the two econometric methods or combining their results occupies an important part of the discussion to follow. Once a decision has been made, the chosen forecasting method will be used to provide input into MAGNET in order to assess the effects of yield changes on land use and other economic indicators.

2.3. MAGNET methodology

In order to use MAGNET for dynamic analyses the model must be updated from 2007 (the most recent year for which GTAP data is available) to 2010, using readily available economic data. The model projects forward until 2020 while incorporating alternative wheat productivity shocks based on econometric forecasts. MAGNET results show the effects of changes in wheat yields on the quantity of wheat produced, real market prices for wheat, and land used to grow wheat and other crops, holding all else in the model constant. The shocks are implemented in two scenarios, namely, a low yield and high yield scenario, and results are compared to a baseline or business as usual scenario. Development of the business as usual scenario is the starting point of a dynamic CGE analysis. In a sense, it forms the backdrop to which other scenarios are compared. The baseline models a future in which socio-economic drivers continue to follow current trends assuming that no policy changes. For the current study, the mean of projected yields is incorporated into the baseline and forms the point of comparison for the low and high yield scenarios. Data for running the baseline, low, and high scenarios are taken primarily from the last three columns of Table 5. For reasons which will be explained, some of the data used in the MAGNET scenarios are adjusted to reflect additional econometric results.

3. Results and discussion

3.1. Current state of European yields

Crop yields in Europe are expected to increase, however, they are expected to do so at a decreasing rate [32,34,45]. The intent of the analysis in this section is to present the broad path that yields have followed over the last 50 years in order to identify general trends and to compare world and European yield rates. If yields in Europe are increasing at a decreasing rate, then the argument that less land will be needed to grow the same amount of wheat diminishes in importance accordingly. Finally, note that yields are rates, they measure an amount of output per area and are not the amount of wheat produced. The difference is fundamental, for instance, several smaller countries, such as the Netherlands, have very high yields but are not large producers. Therefore, an increase in yields in the Netherlands has less of an impact on land use than an increase in, say, the Ukraine.

3.1.1. European trends

Fig. 2a and b presents yields through time for the 43 European countries for which data is available. The Whittaker–Hodrick–Prescott (WHP) smoothing filter was used to derive a smooth-curve representation of yields which is more sensitive to longer term fluctuations [30]. There are several trends to note in Fig. 2a. The figure clearly shows a general leveling of yield rates beginning in the 1990s and continuing unabated until the present. The trend is particularly evident in the higher yield countries; econometric analyses to follow confirm that trend. Another outstanding feature is the sharp drop and then recovering of yields for many countries

beginning in the mid-1990s, these are Central and Eastern European countries undergoing market rationalization in which less efficient farmers and techniques were forced out of the market to the benefit of more efficient farming techniques [36]. How yields in these newer countries develop is really at the core of the matter, if their yields eventually reach the same levels as those in Western Europe, then wheat output can be significantly expanded without using more land. Finally, there appears to be greater variance or volatility in yields of many of the newer countries. Yields for high-yield countries such as the Netherlands, Germany and France appear to be relatively immune to major fluctuations, while those countries with lower yields have experienced large fluctuations. Large fluctuations and short time series make forecasting difficult as will become apparent in later discussions.

3.1.2. Histogram world

A histogram of changes in world wheat yields is presented as a point of contrast to European yield changes. In effect, the next two sections are meant to give an impression of historical yield increases. 3a and b show logged wheat yields in 1961 and 2010 for both world and European aggregations for countries with data in both 1961 and 2010. In both figures, the darker histogram represents yield data in 1961 and the lighter 2010, while the gray area in the middle represents the intersection of the two periods.

Fig. 3a shows that the world's entire distribution has shifted to the right and the mean of the data has increased from 13,439 to 30,881. However, in 2010, there was still a group of countries with low yields including Venezuela, Honduras, Burundi, Libya and Ecuador. The average growth rate over the entire period was 1.7% and the standard deviation increased from 8940 in 1961 to 20,030 in 2010. Table 1 shows that developed countries continue to dominate the top yield positions. Most importantly for the current analysis, European countries are well-represented in the list of the world's most productive wheat producers. This, along with the results in Fig. 2b, suggest that non-European countries might view European yields as a benchmark with the proviso that once the benchmark has been achieved, increases in yields slow.

3.1.3. Histogram Europe

Data for Fig. 3b was constructed using only those European countries for which data was available in 1961 and 2010. As a result, there are 23 countries represented in the figure. The mean in 1961 was 21,178 and 47,256 in 2010, both are around one-and-a-half times greater than their world average equivalents. The average

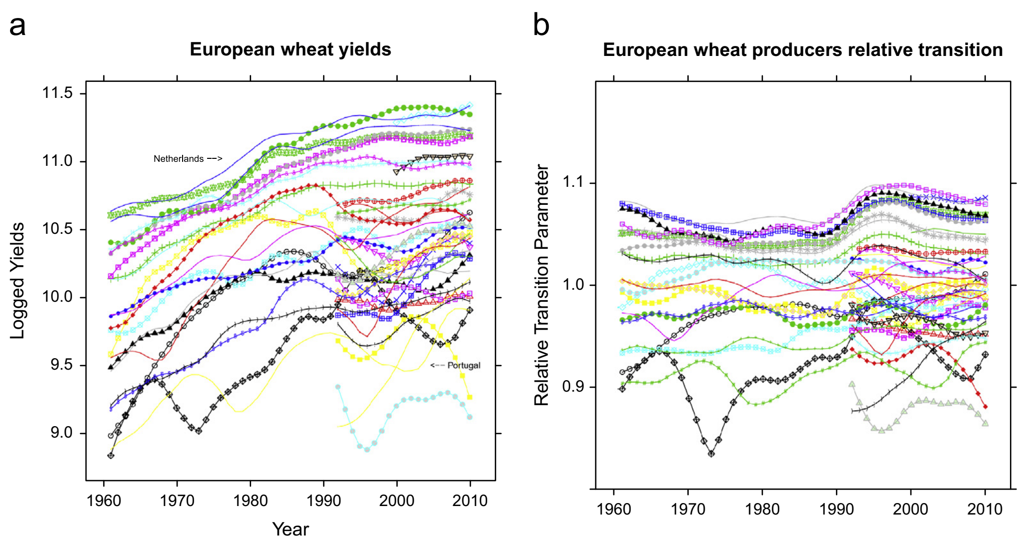

Fig. 2. Wheat yields. (a) Wheat yields and (b) yields.

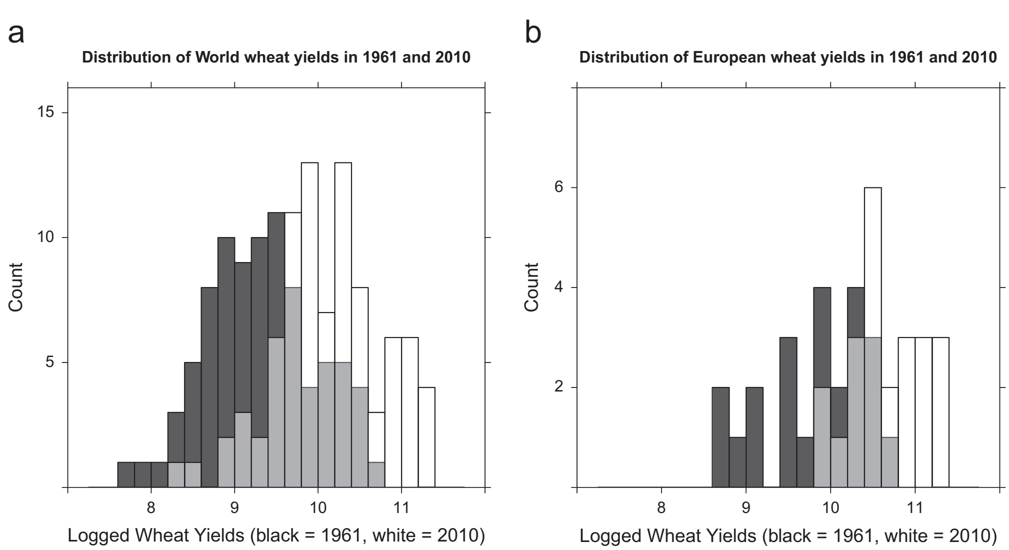

Fig. 3. Wheat yields. (a) World wheat yields and (b) European wheat yields.

Table 1
World top 20 wheat yields in 1961 and 2010.

Country[a]	Yield (1961)	Country	Yield (2010)
DNK	41,205	NLD	89,092
NLD	39,251	IRL	85,990
GBR	35,372	NZL	81,241
IRL	33,676	GBR	76,810
NZL	33,517	DEU	73,102
SWE	32,627	FRA	70,415
DEU	28,607	DNK	66,264
NOR	28,300	NAM	65,789
JPN	27,455	SAU	65,000
CHE	27,134	ZMB	63,118
AUT	25,802	CHL	57,658
NCL	25,000	CHE	57,377
EGY	24,697	EGY	55,741
FRA	23,950	MEX	54,185
KOR	22,657	SWE	54,029
POL	19,929	AUT	50,117
FIN	19,436	MLT	48,519
ITA	19,103	CHN	47,485
HUN	19,095	NOR	40,648
NGA	17,778	ALB	39,905

[a] Complete list of ISO 3 country codes used in this paper: Albania (ALB), Armenia (ARM), Austria (AUT), Belarus (BLR), Belgium (BEL), Bulgaria (BGR), Chile (CHL), China (CHN), Croatia (HRV), Cyprus (CYP), Czech Republic (CZE), Denmark (DNK), Egypt (EGY), Estonia (EST), Finland (FIN), France (FRA), Georgia (GEO), Germany (DEU), Great Britain (GBR), Greece (GRC), Hungary (HUN), Ireland (IRE), Italy (ITA), Japan (JPN), Kazakhstan (KAZ), Korea (KOR), Kyrgyzstan (KGZ), Lithuania (LTU), Luxembourg (LUX), Macedonia (MKD), Malta (MLT), Namibia (NAM), Netherlands (NLD), New Caledonia (NCL), New Zealand (NZL), Nigeria (NGA), Norway (NOR), Poland (POL), Portugal (PRT), Romanian (ROU), Saudi Arabia (SAU), Slovakia (SVK), Slovenia (SVN), Spain (ESP), Sweden (SWE), Switzerland (CHE), Tajikistan (TJK), Turkey (TUR), Turkmenistan (TKM), Ukraine (UKR), Zambia (ZMB).

Table 2
European wheat yields in 1961 and 2010.

Country	Yield (1961)	Country	Yield (2010)
DNK	41,205	NLD	89,092
NLD	39,251	IRL	85,990
GBR	35,372	GBR	76,810
IRL	33,676	DEU	73,102
SWE	32,627	FRA	70,415
DEU	28,607	DNK	66,264
NOR	28,300	CHE	57,377
CHE	27,134	SWE	54,029
AUT	25,802	AUT	50,117
FRA	23,950	MLT	48,519
POL	19,929	NOR	40,648
FIN	19,436	ALB	39,905
ITA	19,103	POL	39,432
HUN	19,095	HUN	37,221
BGR	15,416	ITA	36,997
MLT	13,746	BGR	36,032
ROU	13,438	FIN	34,299
GRC	13,026	GRC	31,373
TUR	9093	ESP	29,417
ESP	8837	ROU	27,000
ALB	7731	TUR	24,411
PRT	6515	CYP	19,956
CYP	5793	PRT	18,493

growth rate over the entire period was 1.6% compared to a world average of 1.7. The data for 2010 appears to be less widely distributed, but this is due to the log scale, in fact, the standard deviation has increased from 10,757 in 1961 to 20,869 in 2010. In 1961, Denmark, the country with the highest yield at the time, had a yield of 41,204 compared to 5792 for Cyprus, the country with the lowest yield. While in 2010, the Netherlands, the country with the highest yield in that year, had a yield of 89,092 compared to Portugal with a yield of 18,493. The significance of which is that in 1961 the highest yield was 7.11 times greater than the lowest yield, while that number was 4.81 in 2010. Great deviations in yields, even among the 23 established European countries, persist, but differences between top and bottom producers appear to be diminishing. This topic will be revisited below using two models of convergence. Table 2 confirms the observation that countries with top yields tend to stay on top. Denmark, the Netherlands, the United Kingdom and Ireland have the top spots in both years; while Cyprus, Portugal, Spain and Turkey occupy the bottom of the table in both years. The relative positions remain fairly stable, suggesting that general technological improvements affect country yields more or less equally. The histograms show that yields in Europe are high relative to the rest of the world, but the decreasing rate of European increases suggests that there are limits to the rate at which yields can economically increase. However, they also suggest that there are potential increases available both globally and within Europe. The next section asks if there is any evidence that European yields are converging to common levels. In short, we can presume from the figures that increases in yields are possible, but is there any evidence that those potential increases can be realized?

3.1.4. Growth rates

Table 3 provides a breakdown of yield growth rates for 5, 10-year periods for several aggregations. The table is meant to show how yield growth rates vary among regions and across time. The methodology used to construct the table was, for each aggregation, to split the data by decade and calculate the corresponding average. Percentage increases were then calculated using the standard methodology. Again, only countries with complete data sets were used in the study.

Yield growth rates appear consistently strong for the first three decades in each aggregation. Values range from around 1.5% to over 3% over these three decades. The difference between 1.5 and 3.0 is enormous; a growth rate of 1.5 implies a doubling of yields every 47 years while a rate of 3.0 implies a doubling every 23 years. All regions experienced slower growth in the 1991–2000 decade. While the yields of major wheat producers (second column) continued to top the other aggregations at a rate of 1.3%, that rate was well below the average for the same aggregation in the previous three decade. The contraction in yield rates for European countries with low yields can be seen in the obvious dip that occurs in this period, see Figs. 2a and b. However, yields in all regions were relatively anemic in that decade. The last decade in the analysis, 2001–2010, saw a slight recovery in the growth of yields for the world, the OECD, and Europe as a whole, where Europe's growth was primarily due to the recovery of the yields of countries in the lower half of the European yield table. Europe's top wheat *producing* countries are at the bottom of the table with a growth rate of just 0.32%, corresponding to a doubling of yields every 217 years!

3.2. Convergence and relative transition

Previous sections have given an overview of yield changes across various aggregations. In this section the focus is on whether the yields of individual countries are converging; in other words, whether yields are approaching some common rate. If the countries in Europe are approaching a common rate, then we can conclude that, all else equal, the yields of Central and Eastern European countries will eventually reach Western European rates. Two types of convergence are discussed. The underlying assumption of first type, known as log *t* convergence, is that if there is a common source of sustained yield increase, then with the diffusion of technology and learning across countries, learning through formal education, and on-the-job learning, it can reasonably be

supposed that all countries ultimately come to share in the growth of yields [35]. Note that log t does not test whether countries are approaching a common, absolute, yield level, only whether countries share a common rate of increase. In contrast, the second type of convergence, absolute convergence, tests whether countries are approaching a common yield level.

3.2.1. Transition coefficients

The first step towards understanding the concept of log t is the calculation of the relative transition coefficient. The basic concept behind the procedure to calculate log t is to eliminate the common growth component among countries in the analysis by scaling the data [38,39]. The transformation eases comparison of the relative changes in yields across countries. Changes in yields for each country are then measured relative to the average growth rate of the entire cross-section. This simple comparative method allows a wide range of time paths and heterogeneity to be modeled while maintaining the commonality of the panel. Furthermore, it allows convergence to be analyzed over different time periods and over different geographic areas. In our specific case, the transition path is measured by considering the relative share of wheat yields of country i in total wheat yields in a specific year, where $\overline{\log y_t}$ denotes the cross-section average of yields in the entire panel or a subset thereof (see Eq. (1)). The quantity h_{it} eliminates the common growth component and provides a measure of each country's share in common growth and technological progress. Because h_{it} is time dependent, it describes how a country's share evolves over time. In effect, h_{it} is a time parameter that traces a transition curve for a country, indicating that country's share of total yields in period t:

$$h_{it} = \log y_{i,t} / \overline{\log y_t} \tag{1}$$

3.2.2. Transition figures

Fig. 2a, at the beginning of the paper, traces individual European country trajectories relative to their cross-section average. The data has once again been filtered using the WHP method to reduce short-term fluctuations and then logged for convenience. If there was convergence, then the figure would have a funnel-like shape with the stem of the funnel on the right hand side of the figure (see [38,39] for an example). However, in Fig. 2a the spread remains relatively stable. In short, there is no visual evidence of either convergence or divergence for yields across Europe.

Fig. 4a and b shows transition paths for yields of the top world and European wheat producers. In Fig. 4a Germany and France lead the pack, far outpacing other world wheat producers. In addition to the initial drop and subsequent recovery of yields as seen in the European figure as well, the outstanding feature in Fig. 4a is the steady progression of China to the extent that it has moved onto a higher trajectory surpassing major producers such as the United States, Canada and Pakistan. It is also possible to discern what appears to be convergence among countries other than China, Germany and France. For instance, the spread between the US, Canada, Turkey, Pakistan, Iran, and perhaps Ukraine and the Russian Federation appears to be less in 2010 than it was in 1960, an indication of convergence. Australia fell out of the group in the late 1990s, but may be bouncing back in recent years so

Table 3
Yield growth rates in five periods.

Period	World (85)	Major world producers (10)	OECD (26)	Europe (23)	Top Europe (17)	Bottom Europe (6)	Europe's top producers (8)
1961–1970	1.70	3.41	1.71	2.08	1.83	3.20	1.91
1971–1980	1.83	1.45	1.54	1.91	1.74	2.50	1.53
1981–1990	2.12	2.33	2.28	2.18	2.25	1.93	2.57
1991–2000	0.36	1.30	0.39	0.17	0.47	−1.20	0.40
2001–2010	0.87	0.80	0.48	0.50	0.42	0.84	0.32

Note: The numbers in brackets are the number of observations, only those countries with complete data sets over the entire period are included in the analysis. Top *producing* countries are distinguished from countries with high *yields*. Top and bottom Europe are those countries in the top half and lower half of an ordered European *yield* table.

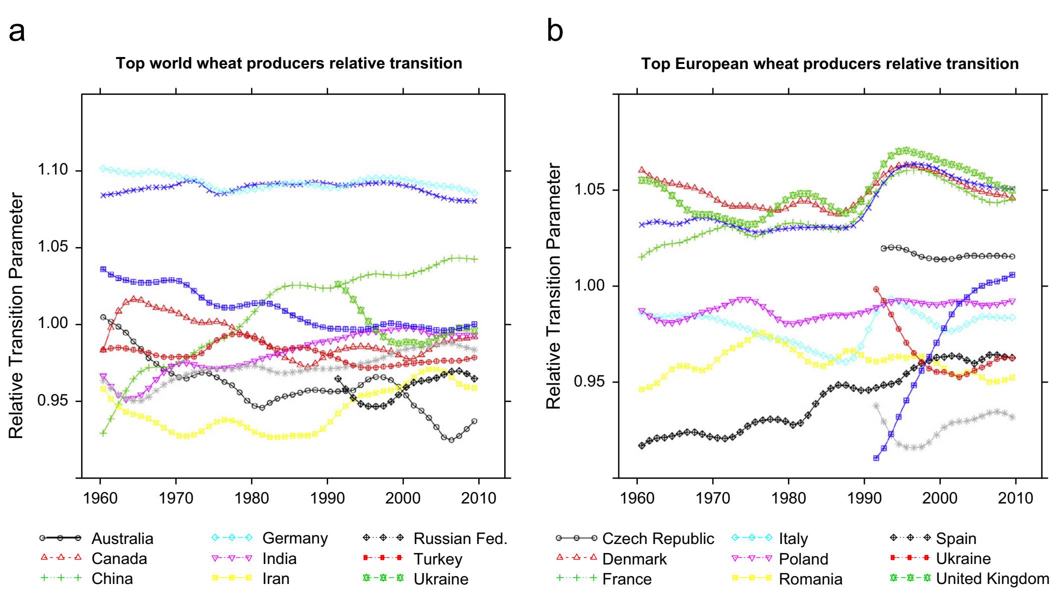

Fig. 4. Wheat yields. (a) Yields of major world wheat producers and (b) yields of major European wheat producers.

perhaps it will rejoin the others. Fig. 4b shows what again appears to be a remarkable degree of convergence among top European producers. Germany and France joined with the United Kingdom and Denmark to form a tightly knit group, while Spain joined Italy, Poland and Romania to form another group. Trends among the newer members of the top European producers vary, Uzbekistan has seen remarkable increases in yields relative to the others, while yields in the Czech Republic, Ukraine and the Russian Federation have stabilized since early 2000.

The essential conclusion of these figures is that with few exceptions, there is little visual evidence that the yields of wheat producing countries in Europe or the rest of the world are converging to one common growth rate. No evidence, in short, that the yields of Central and Eastern European countries will converge to a common source of sustained yield increase. The log t regression test provides a more systematic test of these findings.

3.2.3. Log t regression test

The corresponding regression test of convergence is called the log t test because it is based on a time series linear regression of a cross section variance ratio of the transition parameter on log t (time). Simply put, the test asks whether sample countries are converging to a common source of sustained yield increase.

Formally, the 'log t' regression model is defined as

$$(\log H_1/H_t) - 2\log(\log t) = \alpha + \gamma \log t + u_t \quad \text{for } t = T_0, \ldots, T \qquad (2)$$

where $H_t = N^{-1}\sum_{i=1}^{N}(h_{it}-1)^2$ and $h_{it} = \log y_{it}/N^{-1}\sum_{i=1}^{N}\log y_{it}$ as before.

The convergence test for top world wheat producers from 1961 to 2010 gives a point estimate of -0.74 with a standard error of 0.19, where standard errors are calculated using an automated heteroscedasticity autocorrelation-consistent (HAC) procedure, and is therefore highly significant. A significant negative number such as this implies *divergence* of yields. In other words, there is a strong statistical evidence that yield rates among the top world producers are diverging from one another. Similarly, tests of top European wheat producers return an estimate of -0.90 and a standard error of 0.27. For all European wheat producers the estimate is -0.84 with a standard error of 0.15. In both cases then, despite hints to the contrary in the figures, there is a strong evidence of divergence among these countries. Results for subsets consisting of only, for instance, Denmark, the United Kingdom, Germany and France were not significant. The results confirm the impression that there is no evidence of a convergence of yield rates within Europe, a result which implies that yield rates will vary across Europe.

3.2.4. Absolute convergence

Absolute convergence is the more obvious type of convergence, it tells us whether yields are converging towards a common level [7]. Fig. 5a and b illustrates this type of convergence. The figures show growth rates versus initial yield levels. There are 85 countries represented in the world figure and 23 in the European figure. The working hypothesis is that countries with lower initial yield rates will increase their yields at a faster rate than countries with higher initial rates. The reasoning behind absolute convergence is that countries with lower initial rates will be readily able to adapt and implement extant technologies. The hypothesis is supported by the data, Fig. 5a shows a downward trend which is statistically significant. In other words, lower initial yield rates are correlated with higher growth rates over the period 1961–2010. Data for Europe also show a highly significant negative trend. The importance of this finding for the current study is that we can expect, on an average, that new European countries with lower initial yields will increase their yields at higher rates than established European countries. In short, although there is not a common yield rate among countries, we can expect, on an average, that countries with lower yields will catch-up to world and European averages.

3.3. Real per person GDP

Results of previous sections have been mixed. We have seen that, on an average, European yield growth rates have slowed over the last decades, but that they continue to increase. Although we have to reject a common source of convergence among European countries, we can expect, on an average, that countries with lower yields will increase their yields at a faster rate than countries with higher yields. In this section we begin the process of developing a model to forecast yields. The argument, as outlined in Section 2.1.2, is that as Central and Eastern European countries develop economically, driven by increases in increases in the productivity of capital, labor and land, so will their yields. Yields, after all, are a measure of partial productivity, namely, the productivity of land. Land is only one input in the agricultural production process, labor is of course another important input. At this point we may be

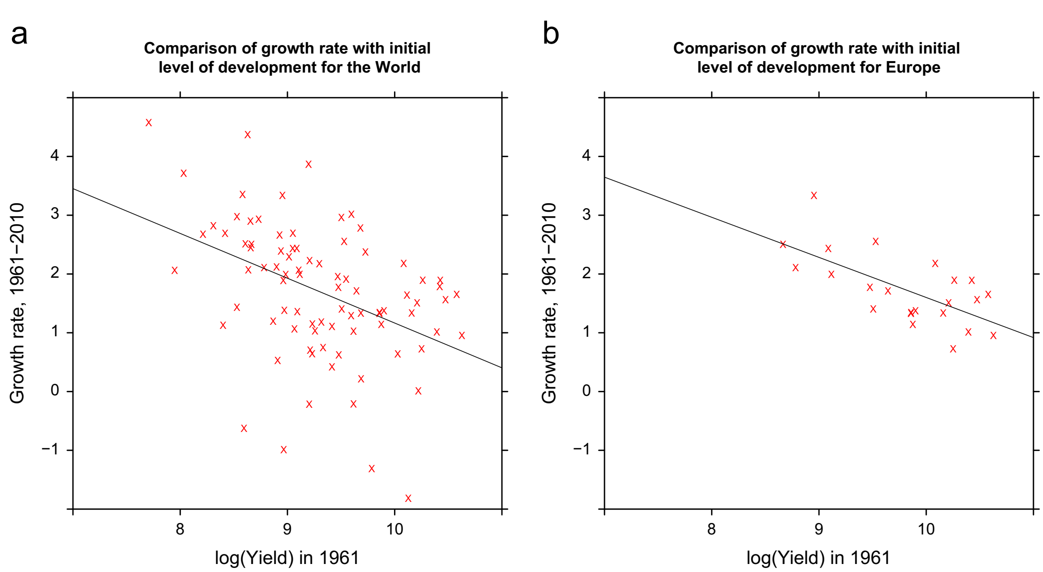

Fig. 5. Yields convergence. (a) Convergence world and (b) convergence Europe.

accused of including an endogenous variable on the right hand side of the equation since GDP per person is driven in part by yields. However, agricultural production, as has just been argued, is only partially driven by yields, and given that agricultural production makes up only a small percentage of GDP for European countries, we argue that yields have only a small impact on the real GDP per person of most European countries [9]. For instance, the agricultural sector represents only 1.8% of the GDP of countries in the European Union, although it constitutes a larger percent of Eastern European countries such as Kazakhstan (5.2%), Turkmenistan (7.6%), and Macedonia (9.6%), and especially Uzbekistan (18.5%), Kyrgyzstan (20.2%) and Tajikistan (23.3%). However, if the general argument is accepted for the 43 countries in the following analyses, then it follows that real GDP per person can be used as an exogenous variable to explain yields.

3.3.1. LOESS regression

In the following sections we begin to examine the relationship between yields and real GDP per person. Locally weighted or LOESS regressions are a method of regression which use a smoothing procedure to average independent variables in a moving fashion [10–12]. Rather than giving all points equal weight in determining the shape of the fitted line as with linear regression, the weights of points close in time receive greater weight than points further away. In a sense, the figures give insight into local relationships within a wider time frame. Fig. 6a and b plot logged yields against logged real GDP per person. The data set consists of 64 countries for which there is yield and GDP data for years common to the two data sets in the period from 1961 to 2009. The data for each country is then split across six periods. In other words, there are 64 country observations for 1961, 64 for 1971, and so on.

The striking feature of Fig. 6 is that the relationship between yields and GDP is flat until logged GDP per person reaches a level of between around 3000 and 8000 dollars per person, after which yields rise steadily with the GDP variable. The implications for the current study are that steady yield increases can be expected for countries which reach that threshold. Fig. 6b implies an even more striking relationship between yields and GDP. The data is split as in the previous analysis and consists of 17 European countries. The European case appears to be similar to the world case, yields seem fairly stable in relationship to real GDP per person and then rise after a GDP threshold is met. However, after a given GDP level is reached, yields fall again. The figure confirms that yields for each decade have increased, although the increase from 2001 to 2009 is small as previously observed in Fig. 4b. Furthermore, it is also possible to see increases in real GDP per person over the decades as the curves shift to the right. In most years, for a given real GDP per person, yields have increased. However, those European countries with the highest yields continue to achieve higher yields and GDP in every decade, but higher yields across that group are *negatively* correlated with GDP in any given decade. The odd relationship pictured is almost entirely due to Switzerland and Norway, both of whom have high real per person GDPs and high yields, but their very high GDP in a sense 'outweighs' their high yields. Removing these two countries reestablishes the positive correlation between yields and GDP. The implication is that there are countries with characteristics which exclude them from the general correlation relationship, data for these exceptional countries should be considered for removal or modification from econometric analyses intended to detect common relationships between yields and GDP. As a consequence, the econometric models to follow were run both with and without Switzerland and Norway included in the models. However, removing either or both countries did not significantly alter the statistical significance of the basic underlying relationships.

3.3.2. GDP transition

Fig. 7a and b is important for further establishing and reinforcing the apparent relationship between yields and GDP. Fig. 7a shows the relative transition of real GDP per person for all European countries in the study. Once again, there is a significant statistical support for divergence among these economies due to the large divergence that occurred in the 1990s as Central and Eastern European economies joined Europe. Just as for yields, the convergence tests for the PWT data show strong evidence of divergence with an estimate of -1.27 and a HAC standard error of 0.27. Subsets of the data, for instance using only data for countries with 60 years or more of data, also show divergence. There does not appear to be a common source of European economic GDP per person growth, and it is therefore difficult to presume that all European countries will ultimately come to share in equal economic development rates. However, the strong correlation between yields and real GDP per person implies a causal

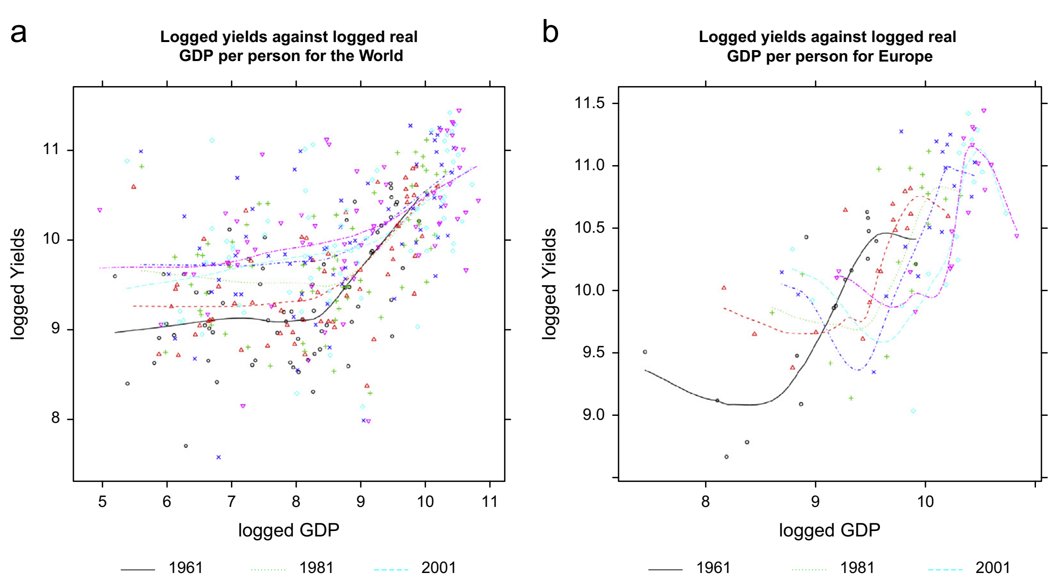

Fig. 6. Wheat Yields versus GDP. (a) World yields versus GDP and (b) European yield versus GDP.

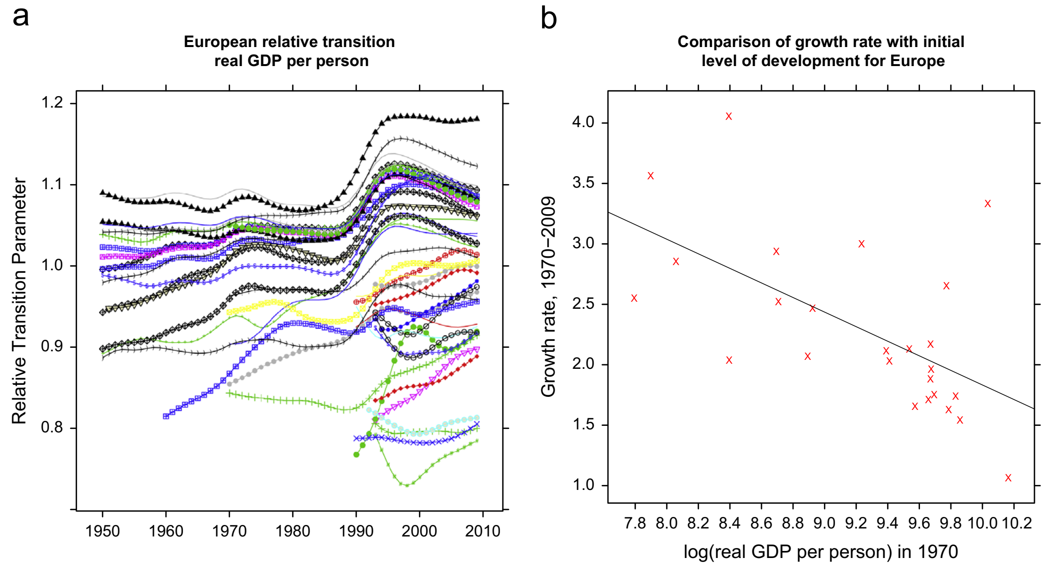

Fig. 7. European convergence of real GDP per person. (a) Real GDP per person European transition parameters and (b) real GDP per person convergence Europe.

relationship in the sense that increases in real GDP are highly correlated with positive changes in yields – a relationship explored in greater detail below. Incidentally, the divergence of Europe's real GDP per person result contrasts sharply with results reported by Sul and Phillips for US states [39]. There does not appear to be a common source of sustained real GDP per person growth in Europe as there is across US states.

3.3.3. *GDP absolute convergence*

Fig. 7b illustrates the idea of absolute economic convergence for 25 European countries for the period from 1970 to 2009. Along the *x*-axis is logged real GDP per person for each country in 1970. Along the *y*-axis is the average growth rate for each country in the study over the entire period. Just as with yields, there appears to be absolute convergence in Europe in that countries with lower initial levels of real GDP per person, on an average, have higher growth rates than countries with higher initial GDP per person levels. Fig. 8 shows the distribution of real GDP per person for 43 countries in Europe. If the argument made in relationship to Fig. 6a and b is accepted, then the countries at the bottom of the distribution such as Tajikistan, Kyrgyzstan, Georgia, Armenia, and Ukraine can expect, on an average, large increases in yields as their economies grow beyond the log GDP per person 'activation' rate. While the yields of more established counties will continue to grow at rates similar to those they have experienced in the recent past.

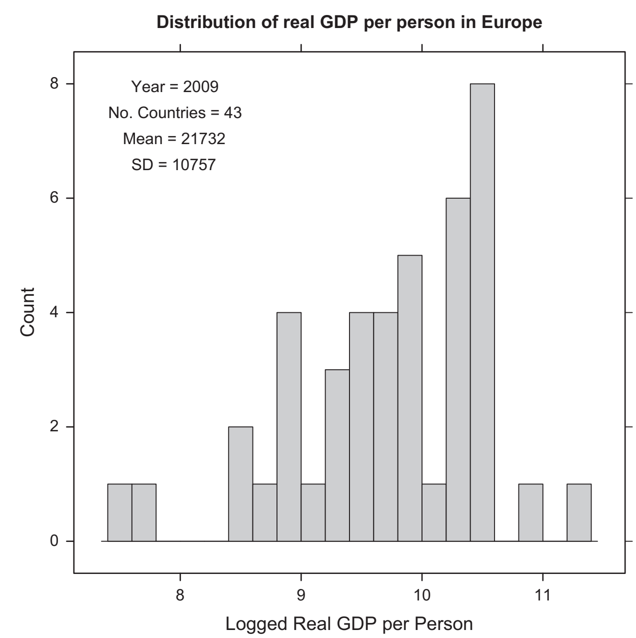

Fig. 8. Real GDP per person, Europe.

3.4. *Econometric model*

In previous sections we have examined yield and real GDP per person developments through time and sought relationships between those two variables. In this section we use econometric models to attempt to quantify the influence of real GDP per person on yields. If that relationship is statistically significant, it can then be used to forecast future yields. The data used in the analysis has a panel format, meaning that it is composed of sets of countries observed over consecutive years. The panels used in the study were complete in that data was available for all countries in all periods. The panel structure allows economic effects that cannot be distinguished with the use of either cross-section or time series data alone to be identified, in short, it allows patterns across time and observations to be discerned and untangled [5,40,56].

Panel data is commonly used to estimate *dynamic* econometric models because of its many advantages over other forms of data [8]. For example, even in cases when the coefficient on the lagged dependent variable is not of direct interest, including that it may be crucial for recovering consistent estimates of the exogenous variables. Improvements in agricultural yields are a dynamic process, and one of the advantages of panel data is that it allows insight into the dynamics of adjustment, in other words, it shows how yields have changed through time. Finally, at a practical level, the use of stochastic dynamic models is an appropriate econometric technique for the case at hand given the small number of years and the large number of countries available in the study. These estimation methods do not require the time dimension to become large in order to obtain consistent estimates. This advantage allows us to make estimates despite the small number of observations available for Central and Eastern Europe.

3.4.1. Dynamic panel model

This section outlines the rationale underlying our choice of which dynamic panel model to use. Only the essential features of the chosen model are described, the interested reader is directed to accompanying references for details. Dynamic relationships are characterized by the introduction of a lagged dependent variable among the regressors, i.e.:

$$y_{it} = \alpha y_{i,t-1} + x'_{it}\beta + (\eta_i + \upsilon_{it}), \quad |\alpha| < 1, \quad i = 1, 2, \ldots, N, \ \ t = 2, 3\ldots T \tag{3}$$

where, in the case at hand, y_{it} is the yield for country i in year t, and $y_{i,t-1}$ is a yield observation for the same country in the previous year, η_i is an unobserved country-specific time-invariant effect that allows for heterogeneity in the means of the y_{it} series across individuals, and υ_{it} is a disturbance term. Individual effects η_i are treated as stochastic, which implies that they are necessarily correlated with the lagged dependent variable $y_{i,t-1}$ unless the distribution of the η_i is degenerate. The disturbances υ_{it} are initially assumed to be serially uncorrelated. These assumptions jointly imply that the Ordinary Least Squares (OLS) estimator of α in Eq. (4) is inconsistent since the explanatory variable $y_{i,t-1}$ is positively correlated with the error term $\eta_i + \upsilon_{it}$ due to the presence of individual effects (see [8] for details).

In short, the presence of the $y_{i,t-1}$ term on the right-hand side of the equation means that there is an endogeneity problem, in essence, we are trying to explain yield changes with a highly correlated version of the same variable! The techniques outlined below are simply a means to overcome the endogeneity issue. The basic first-differenced Two Stage Least Squares (2SLS) estimator for the $AR(1)$ panel model was proposed by Anderson and Hsiao [1,2] to address the problem. The data is first differenced in order to remove η_i from the error term and any other time invariant characteristics of the data [8]:

$$\Delta y_{it} = \alpha \Delta y_{i,t-1} + \beta' \Delta x_{it} + \Delta \upsilon_{it}, \quad |\alpha| < 1, \quad i = 1, 2, \ldots, N, \ \ t = 2, 3\ldots T \tag{4}$$

where $\Delta y_{it} = y_{it} - y_{i,t-1}$. The dependence of $\Delta\upsilon_{it}$ on $\upsilon_{i,t-1}$ implies that OLS estimates of α in the first-differenced model are inconsistent. However, consistent estimates of α can be obtained using 2SLS with instrumental variables that are both correlated with $\Delta y_{i,t-1}$ and orthogonal to $\Delta \upsilon it$. The resulting 2SLS estimator is consistent in large N, fixed T panels, and identifies the autoregressive parameter α provided that at least three time series observations are available [8]. Additional instruments are available when the panel has more than three time series observations. Hansen [24] provides a convenient framework for obtaining asymptotically efficient estimators when $T > 3$, while first-differenced GMM estimators for the $AR(1)$ panel model were developed by Holtz-Eain et al. [31] and Arellano and Bond [3].

Rather than the level values, lagged values of y can be used. In this way the endogeneity issue is addressed by noting that all values of $y_{i,t-k}$, with $k > 1$ can be used as instruments for $\Delta y_{i,t-1}$. In the language of general method of moments (GMM), this amounts to use the relation as an orthogonality condition. In turn, autocorrelation is addressed by noting that if $\Delta v_{i,t}$ is white noise, then the covariance matrix of the vector whose typical element is $\Delta \upsilon_{it}$ is proportional to matrix Hthat has 2 on the main diagonal, -1 on the first sub-diagonals, and 0 elsewhere.

In practice, the one-step GMM estimation of equation amounts to computing

$$\hat{\gamma} = \left[\left(\sum_{i=1}^{N} W'_i Z_i \right) \left(\sum_{i=1}^{N} Z'_i H Z_i \right)^{-1} \left(\sum_{i=1}^{N} Z'_i W_i \right) \right]^{-1}$$

$$\times \left(\sum_{i=1}^{N} W'_i Z_i \right) \left(\sum_{i=1}^{N} Z'_i H Z_i \right)^{-1} \left(\sum_{i=1}^{N} Z'_i \Delta y_i \right) \tag{5}$$

where

$$\Delta y_i = [\Delta y_{i3} \cdots \Delta y_{iT}]' \tag{6}$$

and Z_i is defined as in [5]. In essence, the additional differenced exogenous variables are available as instruments. Once the one-step estimator is computed, the sample covariance matrix of the estimated residuals can be used instead of H to obtain two-step estimates which are both consistent and asymptotically efficient. Standard GMM theory applies, except that Windmeijer [54] has computed finite-sample corrections to the asymptotic covariance matrix of the parameters.

3.4.2. Panel results

The results in Table 4 are calculated using the one- and two-step Arellano-Bover version of the GMM model [5] described above. Three aggregations are shown in the table, Europe as a whole, and the partition of that data into rich and poor Europe. Rich and poor sets were obtained by ordering all European countries by real GDP per person and then splitting the result into two more or less equal groups. The Europe data consists of 43 countries, with rich and poor consisting of 22 and 21 countries respectively. Results confirm the story presented so far. In both models and in all aggregations estimates on lagged yields are significant at the 5% level. This confirms the observation in Fig. 2b that, on an average and after accounting for the effects of real GDP per person, increases in yields are declining for rich Europe. Additionally, and perhaps surprisingly, results also suggest that yields in Central and Eastern Europe are declining at approximately the same amount.

Results for the effects of changes in real GDP per person are mixed across the different aggregations. For rich Europe, increases in real GDP per person are positive but insignificant, meaning that no statistical relationship can be drawn between the two variables at generally accepted levels of significance. This result confirms what can be observed in Fig. 6b, recalling that data used in the regressions only runs from 2001 to 2009. The richer countries are at the relatively flat section of the relationship near the top of the figures. In contrast to rich Europe, for poor Europe there is a significant positive relationship between increases in real GDP per person and yields. This too can be observed in Fig. 6b, where the generally poorer Central and Eastern European countries are at the beginning of the positive effects of GDP on yields. Each one U.S. Dollar increase in real GDP per person leads to an increase of 2.03 hg of wheat produced per hectare (or 0.203 kg per hectare). The European aggregation as a whole appears to be primarily driven by the relationship in poorer Europe. Observations in those countries mean that higher real GDP per country for European countries taken as a whole are positive and significant, although, unsurprisingly, the effect of an increase in GDP is smaller for Europe (0.611) then it is for exclusively poor countries. The implication for the analysis in its entirety is that real GDP per person can be used as a positive predictor of future yields for poor European countries and as a roughly positive indicator for the entire European aggregation.

3.5. Forecasting

3.5.1. Time series forecasting

Previous sections have used historical data to define relationships between yields, lagged yields, and real GDP per person. We now turn to the issue of forecasting yields based on those historical relationships.

Table 4
Dynamic estimates of European wheat yield data for 2001–2009.

Model	Europe		Rich Europe		Poor Europe	
	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error
Arellano-Bover						
Yield	−0.1426	0.0596*	−0.1685	0.0847*	−0.1892	0.0763*
GDP per person	0.6516	0.2926*	0.2167	0.1909	2.0653	0.3809**
Dynamic two-stage						
Yield	−0.1654	0.0673*	−0.1680	0.0855*	−0.1837	0.0789*
GDP per person	0.6112	0.3006*	0.1897	0.1810	2.0310	0.4141**

Note: Estimators for wheat yields across several aggregations.

* Significance at the 5% level.

** Significance at the 1% level.

Forecasting yields for individual countries, as opposed to aggregations of countries, is a straightforward process using standard time series techniques. Given that the data that we are using is reported on a yearly basis, there is no need to correct forecasts for seasonality, although there is clearly a trend which recommends against simple exponential smoothing. As in the aggregate European, poor, and rich country models described directly above (see Eq. (3), the model used to forecast individual country yields is based on an auto-regressive model (a lagged value of yields is included on the right hand side of the equation) and includes real GDP per person. Standard tests confirm the use of an AR(1) specification. The technique used to forecast yields was to use historical relationships to formulate a model and then project that relationship into the future. In general, the further one forecasts into the future, the less one is sure that the relationship holds. The amount of uncertainty is generally measured by the standard error of the residuals which is calculated in the following equation:

$$s_e = \sqrt{1 + \frac{1}{N-2} + \sum_{i=1}^{N} e_i^2} \tag{7}$$

A forecast interval indicates uncertainty through time. It is calculated using the following equation:

$$\hat{y} \pm 1.96 s_e \sqrt{1 + \frac{1}{N} + \frac{(x-\overline{x})^2}{(N-1)s_x^2}} \tag{8}$$

where N is the total number of observations, $\overline{x}$ is the mean of the observed x values, s_x is the standard deviation of the observed x values and s_e is calculated as in Eq. (7).

For those countries in the sample with a complete data set, N is equal to 50. However, for newer countries, data is generally only available from the 1990s onwards. Some other exceptions include Germany, for which PWT data begins in 1970, and Belgium for which the FAO began keeping separate records only in 2000. For Central and Eastern European countries in particular, large variations in yields in the initial decade of their independence make time series forecasting problematic. The large standard error of the residuals, see Eq. (7), means that forecast intervals (8) are at times too broad to make meaningful forecasts far into the future. For this reason, we kept the forecast period to a relatively short 10 year period. Fig. 9 shows time series forecasts for Germany and Poland. The large gray areas represent the amount of uncertainty associated with the forecasts. For Germany the standard error is, relative to that of Poland, small, so that the size of the gray area remains fairly stable though time, while that of Poland increases to reflect the increase in uncertainty through time.

Table 5 contains forecasts for each country within Europe using the methodology described above. An 80% interval is presented in the table meaning, loosely, that we can be 80% confident that the true yield value will lie within the interval. The 80% interval can be constructed by simply replacing 1.96 with 1.282 in Eq. (8). The values in Table 5 are used to calculate the likelihood that yields will reach a particular level in the future from which a rate can then be calculated. The first column in the table is realized yields in 2009; the second contains the predicted mean in 2020. The smallest and greatest 80% columns in the tables are the smallest and greatest yields that can be expected within the 80% interval. The last three columns of the table show how much yields, in percentage terms, would have to improve yearly in order to achieve the mean, smallest and greatest levels of the interval in 2020 using the starting, realized, values in 2009. The negative numbers in the last column for Belgium, Bosnia and Herzegovina, and Kyrgyzstan are a result of the high standard errors for these countries which make forecasting values for those countries dubious. For the remaining countries in that column, the values range from less than 1% for Luxembourg to over 7% for Georgia. Given the average of around 2.79% for countries with non-negative values is at the upper end of the historical values as shown in Table 3, the implication is that a such a large increase over a sustained period is optimistic for the group as a whole, but possible. The large increases required of countries such as Belarus, Turkmenistan, Bulgaria and Georgia would imply particularly impressive, sustained, yield increases.

3.5.2. *Panel forecasting using the best linear unbiased predictor*

As shown above, the large standard errors caused by the small number of observations for some countries in the data set make time series forecasting for those countries difficult. Fortunately, panel forecasting methods allow forecasts to be estimated for the individual members of a panel data set (see [5] for complete argument). The advantage of this approach is that a panel data set can be used to estimate a single, general, model based on a relatively small number of observations and the results can then be applied to the disaggregated members of the set. The *disadvantage* is that a panel model estimates one model for all countries. Therefore, if there is a great deal of heterogeneity within the data, in the sense that underlying relationships vary greatly across countries, then a panel model will be less appropriate.

The methodology used to forecast panel models is intuitive. Suppose that we want to predict S periods ahead for the ith individual of a panel. For the generalized least squares (GLS) model, when the variance–covariance structure of the disturbances is known, Goldberger [43] showed that the best linear unbiased predictor (BLUP) of $y_{i,T+S}$ is

$$\hat{y}_{i,T+S} = Z'_{i,T+S}\hat{\delta}_{GLS} + w'\Omega^{-1}\hat{u}_{GLS} \quad \text{for } s \geq 1 \tag{9}$$

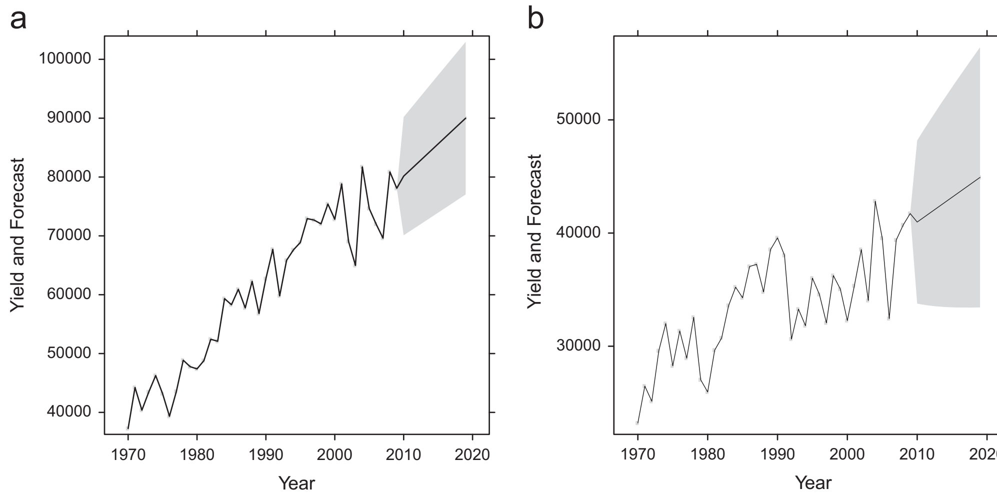

Fig. 9. Yield time series forecasts for Germany and Poland (95% confidence interval). (a) German time series and (b) Polish time series.

Table 5
Forecasts of wheat yields in 2020.

Country	Yield 2009	Mean 2020	Smallest 80% 2020	Greatest 80% forecast	Mean forecast	Smallest 80% forecast	Greatest 80% forecast
ALB	40,229.47	45,027.35	37,580.50	52,474.19	1.13	−0.68	2.69
ARM	22,010.77	21,247.56	17,061.11	25,434.01	−0.35	−2.52	1.46
AUT	49,294.58	58,262.84	51,644.12	64,881.56	1.69	0.47	2.79
BEL	94,651.78	84,444.79	78,326.69	90,562.89	−1.13	−1.88	−0.44
BGR	31,872.94	35,500.23	19,629.24	51,371.21	1.08	−4.73	4.89
BIH	37,751.28	31,855.22	26,690.83	37,019.60	−1.68	−3.41	−0.20
BLR	35,427.60	35,427.60	17,999.37	52,855.83	0.00	−6.55	4.08
CHE	60,232.74	66,835.06	58,544.49	75,125.63	1.05	−0.28	2.23
CYP	25,499.05	17,507.32	7956.98	27,057.66	−3.69	−10.99	0.60
CZE	52,424.76	52,715.43	42,613.14	62,817.72	0.06	−2.05	1.83
DEU	78,090.79	88,447.02	82,038.78	94,855.26	1.25	0.49	1.96
DNK	80,373.43	83,988.66	75,958.78	92,018.53	0.44	−0.56	1.36
ESP	26,721.91	36,062.07	29,419.20	42,704.94	3.04	0.97	4.80
EST	30,146.37	30,671.02	20,623.32	40,718.72	0.17	−3.73	3.05
FIN	41,026.83	38,638.90	28,811.11	48,466.69	−0.60	−3.47	1.68
FRA	74,469.05	81,915.41	73,962.29	89,868.53	0.96	−0.068	1.90
GBR	70,662.65	84,736.04	74,526.69	94,945.40	1.83	0.53	3.00
GEO	10,737.05	15,958.26	10,644.35	21,272.17	4.04	−0.087	7.08
GRC	26,217.77	29,042.38	23,481.78	34,602.97	1.03	−1.10	2.81
HRV	51,895.82	52,883.80	38,343.11	67,424.50	0.19	−2.98	2.65
HUN	38,546.13	39,904.54	29,712.40	50,096.68	0.35	−2.57	2.66
IRL	81,656.80	100,000	87756.30	112,065.08	2.04	0.72	3.22
ITA	35,316.07	35,781.68	26,191.23	45,372.12	0.13	−2.94	2.54
KAZ	11,900.01	11,085.52	5090.74	17,080.30	−0.71	−8.14	3.68
KGZ	26,284.94	22,653.30	19,319.97	25,986.63	−1.48	−3.03	−0.11
LTU	42,004.00	40,440.65	27,220.47	53,660.82	−0.38	−4.25	2.48
LUX	65,676.61	60,815.75	55,106.21	66,525.29	−0.77	−1.74	0.13
LVA	36,275.81	49,473.38	44,635.50	54,311.27	3.15	2.10	4.12
MKD	30,755.98	27,236.46	22,058.26	32,414.66	−1.21	−3.27	0.53
MLT	50,000.00	50,000.00	30,454.24	69,545.76	0.00	−4.84	3.35
NLD	92,911.86	97,710.44	87,778.63	107,642.24	0.50	−0.57	1.48
NOR	34,068.63	47,384.24	39,260.41	55,508.06	3.35	1.43	5.00
POL	41,725.30	44,341.45	38,337.12	50,345.78	0.61	−0.84	1.90
PRT	18,552.19	20,538.25	12,751.18	28,325.32	1.02	−3.68	4.32
ROU	24,304.64	26,285.23	17,965.33	34,605.13	0.79	−2.98	3.60
RUS	23,181.78	23,181.78	12,985.17	33,378.39	0.00	−5.63	3.71
SVK	40,557.23	41,130.65	34,535.38	47,725.92	0.14	−1.59	1.64
SVN	39,643.25	42,627.91	37,822.92	47,432.89	0.73	−0.47	1.81
SWE	60,939.17	68,400.03	61551.30	75,248.76	1.16	0.10	2.13
TJK	26,157.30	34,342.06	28,672.94	40,011.17	2.76	0.92	4.34
TKM	34,394.65	34,394.65	10,873.82	57,915.48	0.00	−10.88	5.35
TUR	25,663.71	26,660.29	23,936.26	29,384.32	0.38	−0.69	1.36
UKR	30,929.53	27,731.35	20,444.71	35,017.99	−1.09	−4.06	1.25

Note: Column year 2009 is the realized yield in 2009 and mean 2020 is the predicted mean value. The low and high 80% columns are the smallest and greatest values of the intervals of the 80% confidence interval, respectively. The last three columns are the *yearly* increases necessary to reach the predict mean, and the low and high end of the confidence interval.

where $\hat{u}_{GLS} = y - Z\hat{\delta}_{GLS}$ and $w = E(u_{i,T+s}u)$. Note that for period $T+S$

$$u_{i,T+S} = \mu_i + \nu_{i,T+S} \tag{10}$$

and $w = \sigma_\mu^2(l_i \otimes l_T)$, where l_i is the ith column of I_N.

In this case

$$w'\Omega^{-1} = \sigma_\mu^2(l'_i \otimes l'_T)\left[\frac{1}{\sigma_1^2}P + \frac{1}{\sigma_\nu^2}Q\right] = \frac{\sigma_\mu^2}{\sigma_1^2}(l'_i \otimes l'_T) \tag{11}$$

A typical element of $w'\Omega^{-1}\hat{u}_{GLS}$ becomes $((T\sigma_\mu^2/\sigma_1^2)\overline{\hat{u}}_{i.,GLS})$, where $\overline{\hat{u}}_{i.,GLS} = \sum_{t=1}^{T}\hat{u}_{it,GLS}/T$. Therefore, the BLUP for $y_{i,T+S}$ corrects the GLS prediction by a fraction of the mean of the GLS residuals corresponding to that ith individual. In practice, the optimal variance components are replaced with their estimated values.

The best quadratic unbiased (BQU) estimators of the variance components arise from the spectral decomposition of Ω [6]. The estimated variance terms can be calculated using the following equations:

$$\hat{\sigma}_1^2 = \frac{u'Pu}{\mathrm{tr}(P)} = T\sum_{i=1}^{N}\overline{u}_{i.}^2/N \tag{12}$$

$$\hat{\sigma}_\nu^2 = \frac{u'Qu}{\mathrm{tr}(Q)} = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T}(u_{it}-\overline{u}_{i.})^2}{N(T-1)} \tag{13}$$

where the sigmas are calculated in the usual manner from the Within and Random effects models.

Fig. 10 presents realized yields versus predicted yields per country. All 43 countries are represented in the figure. Each symbol represents the realized and predicted values of wheat yields for a country in a particular year (2001–2009), so there should be nine symbols for each country. The intention of the figure is not to identify specific points, the figure contains far too much data to do that, rather, it is intended to show general patterns for countries. In general it appears that countries consistently out or under-perform their predicted values. For instance, Germany, Denmark, France, the Netherlands, the United Kingdom and Ireland, countries above the bisector, consistently outperform expectations. In other words, their realized wheat yields outperform what the panel model forecasts they should be. While Spain, Finland, Greece, Italy, Norway and Portugal, those countries below the bisector, consistently under-perform expectations. This suggests that there may be country specific structural effects at work which determine how wheat yields correlate with real GDP per person.

Table 5 presents similar data to that used immediately in Fig. 10. In particular, it shows realized 2009 yields versus predicted yields for the same year. In other words, panel results using lagged yields and real GDP per person are used to forecast 2009 yields which are then compared to realized yields. For instance, Albania, the first country in the table, is performing well above what the model predicts for that year, while Austria, the second country in the table, is performing well under expectation.

Results of the panel forecasting model are disappointing. Unsurprisingly perhaps given the great diversity among countries within the panel under consideration. The Western, Central, and Eastern European countries are on very different economic trajectories. In fact, standard F-statistics soundly reject the null hypothesis that the countries have one common intercept, in other words, when forecasting, a single aggregated model based on data from the entire panel should be rejected in favor of country specific models. Therefore, we shall use forecasts from our time series models Section 3.5.1, as input into MAGNET.

3.5.3. MAGNET results

As is true for any CGE analysis, the results presented here should not be used to make precise predictions about economic

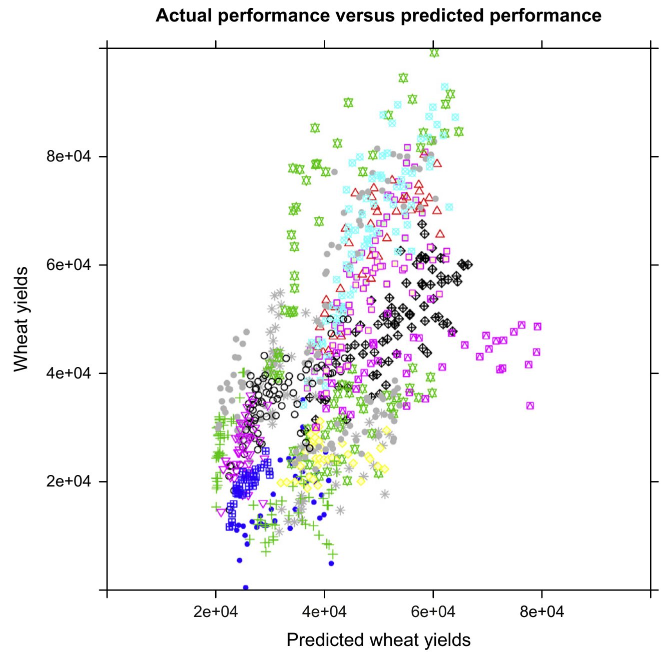

Fig. 10. Relative yield performance.

events. Rather, CGEs are uniquely suited as a means to guide us through the significant effects of a shock to an economy. In the case at hand, MAGNET results give an indication of the economic impacts of changes in yields as they ripple through the European and world economies. In addition, MAGNET, and other CGE models, are deterministic models which show that the changes needed to move from one equilibrium to another [20]. With these qualifications in mind, the MAGNET model can help us to understand the economic implications of yield changes on the amount and price of wheat and land use.

Recall that three MAGNET scenarios were run using top wheat producing regions in Europe. The scenarios consisted of a base scenario which uses the mean of predicted yields, and low and high yield scenarios, all of which were based initially on data found in the last three columns of Table 5. Results from Table 5 were only used when they could be accurately calculated. In some cases, given the small number of observations available, standard errors were too large to make meaningful predictions using standard time series methods. In such cases, yield predictions were made in consideration of the figures, tables and panel forecasts described in the previous sections.

The mean, low and high scenarios for all countries were formulated with regard to the additional information based on the above-described analyses. Twelve top producing European countries, with an equal number of established and newer countries, were chosen for the analysis. Expected yields across all countries show a great deal of variation, from possible negative changes in yields to very positive changes. The main point of running the analyses is to show how changes in yields may affect important economic variables including land use. In the case of the yearly mean shocks, most values appear reasonable in the given data. For established European countries they range from around a tenth of a percent growth in yields for Italy to 3% for Spain. For newer European countries, the range of values is large and never above 1%. In the case of Ukraine, the mean yield change is negative 1%. However, that number is suspect for previously stated reasons so that value was changed to zero in the base or mean scenario. Admittedly, this is a somewhat arbitrary change, another value could have been chosen, but a growth rate of 0% over a 10 year

period is conservative given historical trends. For the lower yield scenarios, values for established Europe range from negative three for Italy to positive 1% for Spain. Given the length of the time series available for these countries, a negative growth rate is probabilistically possible so these numbers were used in the analysis. In the case of newer European countries, the negative numbers were again set to zero. Again, the small number of historical values available makes precise forecasts impossible and zero seems a conservative value. The high forecast values for established Europe range from just about one-and-a-half percent for Denmark to nearly 5% for Spain. Values for new Europe range from around 1% for Ukraine to nearly 4% for Romania and the Russian Federation. Sustained growth rates of 3% and higher have not been experienced since the 1960s, but recall that the high yield scenario is intended to measure effects of yield increases which are high, but probabilistically possible. which are probabilistically unlikely to occur and so these values are used in the analysis. In short, the scenarios are designed to provide pessimistic and optimistic extremes. It is most likely that actual values will occur somewhere between these two extremes – with the mean forecast being the most likely. The scenarios offer an experiment that tests yield ranges from negative to very positive percentage changes in yields (Table 6).

MAGNET scenario results, given that the model assumes perfect competition, should not deviate significantly from what standard economic theory tells us should happen in the event of a shock. The basic idea of a shock is to run an experiment in which one or a few aspects of an economy are changed and then to examine how the rest of the economy adjusts to the shock once the economy has reached a new equilibrium. Standard theory can best be described using a simple supply and demand diagram. For example, in the event of an improvement in the technology used to produce wheat, we would expect the supply curve to shift out from S1 to S2 in Fig. 11. The initial increase in the quantity of wheat produced is the distance $\overline{EC}$. However, at that price supply exceeds demand so firms will reduce their supply while demand will increase as buyers switch from wheat substitutes to the now cheaper wheat *F*. At the new equilibrium equation (2), standard theory says that prices should be lower and the quantity of wheat sold higher than it was in the original equilibrium. In the case of a reduction in the technology used to produce wheat, theory says that wheat prices will rise and the quantity produced will fall.

MAGNET results largely conform to theory as can be seen in Table 7. The first two columns show production quantity and production price for wheat production in Europe and the rest of

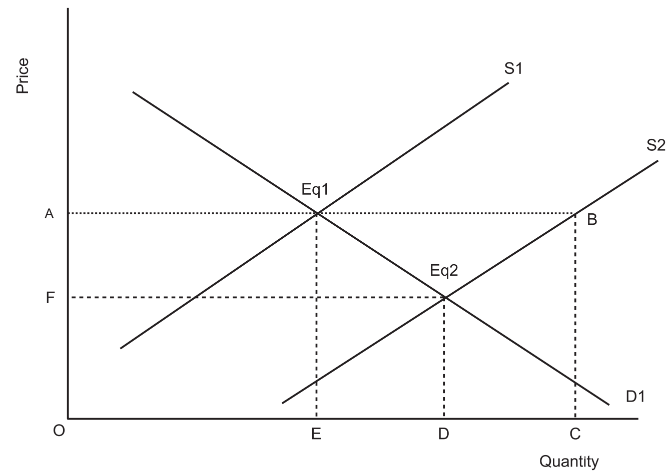

Fig. 11. Supply and demand in the case of technological improvement.

Table 7
MAGNET wheat results land demand, production quantity, production price, and land price.

Country	Prod. quantity		Prod. price		Land use		Land price	
	Low	High	Low	High	Low	High	Low	High
ROW	0.50	−3.36	0.05	−0.34	0.42	−2.83	0.04	−0.17
DNK	−0.48	−0.78	0.89	−0.73	7.38	−7.23	2.96	−2.61
FRA	−1.21	−1.25	0.87	−0.74	6.81	−7.59	4.81	−4.69
DEU	−0.61	−1.76	0.74	−0.71	4.99	−6.20	1.16	−1.21
ITA	−9.52	2.92	4.33	−2.32	16.11	−14.39	6.04	−4.56
ESP	−3.37	0.10	1.65	−1.05	11.68	−10.29	4.33	−3.30
GBR	−0.82	−0.79	0.82	−0.59	8.11	−7.66	5.03	−4.23
CZE	0.87	8.94	0.45	−4.41	1.27	−6.89	0.80	−3.64
POL	−1.80	2.88	1.80	−3.35	3.66	−7.92	1.45	−2.95
ROU	−4.18	14.73	2.61	−7.27	2.59	−9.4	1.25	−4.05
RUS	0.35	27.25	0.08	−7.89	0.33	−6.88	0.01	−0.02
UKR	0.24	3.31	0.03	−2.95	0.22	−7.28	0.07	−2.96
XSU	−0.09	19.20	0.10	−10.76	−0.06	−14.11	0.78	−5.49

Note: XSU is an aggregated region which includes Uzbekistan.

Table 6
Forecasts of wheat yields in 2020.

Country	GDP 2009	Realized yields	Predicted yields	Country	GDP 2009	Realized yields	Predicted yields
ALB	6641.8	40,229	27,626	ITA	27,710	35,316	46,875
ARM	5375.1	22,011	26,468	KAZ	11,734	11,900	32,279
AUT	37,415	49,295	55,743	KGZ	2300	26,285	23,659
BEL	34,630	94,652	53,198	LTU	14,187	42,004	34,520
BGR	10,923	31,873	31,537	LUX	84,585	65,677	98,842
BIH	7116.2	37,751	28,059	LVA	12,776	36,276	33,231
BLR	12,782	35,428	33,236	MKD	7681.5	30,756	28,576
CHE	39,634	60,233	57,770	MLT	21,666	50,000	41,353
CYP	18,997	25,499	38,915	NLD	37,052	92,912	55,411
CZE	21,972	52,425	41,633	NOR	49,980	34,069	67,223
DEU	32,494	78,091	51,246	POL	16,376	41,725	36,520
DNK	33,932	80,373	52,560	PRT	19,904	18,552	39,743
ESP	27,649	26,722	46,820	ROU	9741.4	24,305	30,458
EST	16,295	30,146	36,445	RUS	14,645	23,182	34,938
FIN	32,187	41,027	50,966	SVK	19,145	40,557	39,050
FRA	30,837	74,469	49,733	SVN	24,958	39,643	44,361
GBR	33,407	70,663	52,081	SWE	35,246	60,939	53,761
GEO	5062.6	10,737	26,183	TJK	1872.9	26,157	23,269
GRC	27,304	26,218	46,505	TKM	6934.9	34,395	27,894
HRV	15,085	51,896	35,340	TUR	9919.4	25,664	30,621
HUN	16,521	38,546	36,653	UKR	6413.9	30,930	27,418
IRL	33,406	81,657	52,080				

the world (ROW). In the low yield improvement case, wheat production is less efficient than in the base, mean case and, as a consequence, the quantity produced in European countries falls expect the Czech Republic, the Russian Federation and Ukraine, all of whom experience slight increases in production quantity. However, in all three cases, yields in both the mean and the low yield scenarios were set to zero. In other words, there was no change in wheat yields for these countries. In fact, they are relatively more efficient in the production of wheat given that other countries in the scenarios have seen reductions in their ability to produce wheat; therefore, they will produce more wheat for consumption and export. The other countries all experience a reduction in their ability to produce wheat relative to the base case, and in all cases the quantity produced falls. Since the rest of the world received no shock it is relatively more efficient than Europe in the production of wheat following the low yield shock, and therefore produces more for their own consumption and export to Europe. The price of production in the low yield scenario increases for *all* countries in the world. This is because the production of wheat has become less efficient so that it is more expensive to meet wheat demand.

For the high yield case, in which wheat yields improve, the quantity of wheat produced increases for Italy, Poland, Ukraine and slightly for Spain, but is especially high for the Czech Republic, Romania, Uzbekistan (XSU) and the Russian Federation. The last four countries are driving what is happening in this scenario. The large yield increase they experience, especially when compared to the relatively anemic increases in the rest of Europe, means that their production increases dramatically and it becomes more efficient for many other European and countries in the rest of the world to import wheat from those four countries. The result is a decrease in production quantity for most other countries and a decrease in the price of production for all countries.

3.5.4. Land use

We are now in a position to ask what happens to land use in relationship to exogenous changes in yields. The basic economic mechanisms are the same as those in the previous analysis. However, instead of a shift in the supply curve of wheat, now the demand curve for land shifts as more or less land is needed to grow the same amount of wheat. For example, a technological improvement in the production of wheat shifts the demand curve for land to the left reducing the demand for land and lowering its price at the new equilibrium. This shift is directly modeled in both the low and high scenarios. The low yield scenario models the case that land is less efficient than the predicted mean and, as a result, land use increases in all countries except Uzbekistan, which realizes a slight decrease as a result of the narrow difference between the mean and low scenarios for that country. The high yield scenario leads to a reduction in land used to grow wheat for all countries. Again, the high yield case means that the same amount of land can be used to grow more wheat so less land is needed to meet the demand for wheat. Changes in the price of land follow along the same reasoning; less efficient land used to grow wheat means that more land is needed to grow the same amount of wheat. The additional land must be bought in the perfectly functioning land market, thereby raising the price of land. In the case of more efficient production, the price of land falls because less land is needed to grow the same amount of wheat so the excess land is sold in the market thereby lowering the price of land.

The land ‘freed’ by the increase in wheat yields is not exclusively available for the production of wheat. Other crops, and any other MAGNET sector using land, compete with wheat for land as an input and market prices for intermediate and final products will determine to which use the freed land is eventually allocated. Indeed, MAGNET results show that land use for non-wheat crops and other sectors using land decreases as a result of reduced wheat yields and increases wheat yields improve. These other sectors are harmed by or benefit from decreases or increases in wheat yields. Therefore, the argument that yield increases release land which is currently being used to grow wheat or other crops to grow bio-energy crops should be tempered by the fact that other crops and sectors using land, besides bio-energy crops, compete in the marketplace for the same land. The market value of intermediate and final products will determine to which sector the freed land is allocated.

4. Conclusions

Two complementary methodologies have been used in the foregoing analysis, the first to estimate and forecast yields, and the second to calculate the resulting effects on land use. A wide variety of tools were used to analyze the historical and possible future growth patterns of wheat yields.

We found that yields for the world and Europe have significantly increased in the period from 1961 to 2010. For instance, yields for European countries with the highest yields have more than doubled in that period, while those with the lowest yields have more than tripled in some cases. However, there is strong evidence of a general leveling of yields since the 1990s, a trend which is particularly evident for countries with higher yields, but also extending to Central and Eastern European countries as well. Fig. 2b reaffirms previous observations that growth rates have been decreasing across most of Europe as do panel analyses in Table 4. That table provides strong statistical evidence that yields are increasing at a decreasing rate for both rich (Western) and poor (generally Central and Eastern) European countries alike. However, the table also shows that poorer countries can expect to realize large increases in yields as their levels of real GDP per person increase.

In the last two decades all growth rates except the world's 10 most productive wheat producers have been well below one-and-a-half percent and, in most cases, well below one percent. This trend is the most dramatic in the case of Europe's top wheat producing countries, which have seen yield growth rates of just 0.32% in the last decade, corresponding to a doubling of yields every 217 years. In addition, large differences in yield rates persist within Europe, with high yield countries producing four times the amount of wheat for a given area when compared to European countries with the lowest yields. Our study has found evidence of log *t divergence*, meaning that there is no evidence of a common underlying growth rate for yields across Europe. However, there is strong evidence of absolute convergence which indicates that, on an average, countries with lower initial yields will grow faster than countries with higher initial yields. In short, although European countries have been growing at a variety of rates, those countries with lower initial rates will grow, on an average, at higher rates than countries with high initial growth rates.

The short and erratic time series of many Central and Eastern European countries complicated the forecasting process. For instance, the sharp drop and then recovering of yields for many Central and Eastern European countries undergoing market rationalization increased yield variation, thereby reducing the effectiveness of standard time series techniques for those countries. To address the problem of short series, dynamic panel methods, which *require* short time series relative to the number of observations, were employed to estimate yield developments and included lagged yields and real GDP per person as exogenous variables. Results were consistent with observations based on the

previous figures. Table 4 shows that there is a positive relationship for poorer countries between increases in real GDP per person and yield increases. While estimates for the variable changes in yields are all significantly negative, indicating that yields are increasing, but at a decreasing rate. Finally, Fig. 10 shows that countries are fairly consistent in either under or over performing in regard to estimated yields. However, forecasts using the panel model were rejected in favor of time series techniques because the diversity of countries within the data set raised concerns about the results. A final, perhaps surprising outcome, is the result that some European countries may experience decreases in yields in the coming years relative to their current levels. Although unlikely, the negative values are at the low end of the 80% confidence interval, a contraction in yields is possible.

The technique used to estimate yields resulted in a diverse range of forecast values (see Table 5) that were then used as input into the MAGNET model. The values give a rough indication of what might happen to yields in the future given historical developments in yields and real GDP per person. They indicate a diverse range of growth rates across Europe. In summary, there is evidence that Central and Eastern Europe have at least the potential for growth, although recent evidence indicates that their growth rates are slowing as well. As discussed in the text, forecasts are not perfect indicators given the small number of available years for some Central and Eastern European countries. With that qualification in mind, MAGNET used the calculated growth rates as input and has given us insight into the wider economic adjustments which occur when yields change.

MAGNET results, for the most part, followed what standard economic theory predicts would happen when yields either decrease or increase relative to the business as usual case, although there are a few interesting outcomes which require explanation. The effects of the case in which yields achieve the lower end of the 80% confidence interval are discussed first, followed by the case in which they achieve the highest values of the same interval.

When yields achieved the lower end of their forecasted values, land demand for wheat production increased across the vast majority of regions. The increase implies that the demand for wheat, in a sense, outweighs the higher cost of producing wheat. Recall that yields, which is output per land area, are a part of the cost of producing wheat, a decrease in wheat yields means that more land is required to produce the same amount of wheat. Since the demand for wheat is not perfectly elastic, in other words, demand for wheat does not fall as much as its price rises, more land was required to supply wheat demand. An increase in the demand for land to produce wheat means that, in general, there is less land to produce crops other than wheat. Land has become relatively scarce and therefore more expensive, leading to a decrease in land demand and an increase for other inputs into the production process. The net result is that land demand for agricultural sectors other than wheat fell. The total land demand and supply from all sectors including wheat increased slightly, meaning that the decrease in wheat yields caused additional land to become available for agricultural production.

It is perhaps surprising that the production of wheat decreased in regions in Western Europe, but increased in Central and Eastern Europe. However, this discrepancy is caused by the fact that it becomes relatively cheaper for Western European countries to import wheat from Central and Eastern Europe. Although the price of production increased in all European regions, increases in Western Europe were relatively higher. This difference between Western Europe and Central and Eastern Europe is clearly evident in the effects of a decrease in yields on land prices between the two regions. Land prices for wheat production in Western Europe saw a large increase compared to much smaller increases in Central and Eastern Europe.

When yields achieved the upper end of their forecasted values in Europe, land demand for wheat production fell across all countries, both in Europe and the rest of the world. This is essentially the story that is told in the models mentioned in the introduction of this paper. Higher yields mean more land available to grow wheat or some other bio-energy products. It is self-evident, less land is needed to grow the same amount of wheat. However, MAGNET, and standard economic theory, tell us that land demand from all other sectors, excluding wheat, rose for most regions as a result of the increase in wheat yields. The land freed from the production of wheat went to the production of other agricultural products, and not only the production of bio-energy products. For instance, land used to raise live-stock increased as well. Total land demand from all sectors including wheat decreased slightly for all regions of the world. In short, some of the land freed on account of wheat yield increases either went to the production of non-agricultural products or was idled.

Again, at first glance it may be surprising that wheat production increased by a large percent in Central and Eastern Europe, but fell in many regions in Western Europe. This shifting of production from Western Europe to Central and Eastern was a result of greater production price reductions in Central and Eastern Europe when compared to Western Europe. The price of land used to grow wheat, generally a large percentage of the price of production, fell across all countries because land for wheat production, and the production of all other agricultural products, is now more plentiful.

The principle message, from either a decrease or increase in wheat yields, is that the economic effects of yield changes or any other significant change need to be analyzed with regard to their substitutes and complements, and the marketplace in which they operate. The analysis shows that land released by an increase in wheat yields will not necessarily go to produce bio-energy crops. Rather, it will go to the sector that values additional land the most. To complicate the matter still further, yield changes in wheat need to be analyzed with regard to yield changes in other crops as well, in our analysis we have assumed that the yields of other crops continue along their forecasted paths. Our analysis shows that wheat yields are likely, on an average, to increase, but at a decreasing rate. The effects of those wheat yield increases on the production of wheat is positive, but that increase is mitigated by the demand for other products for land which made relatively cheaper input. A more direct, but economically distorting, manner to increase wheat supply would be to make it more profitable to produce through, for instance, direct subsidies or subsidies to the bio-energy products that use it as an input.

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